Testimony to the U.S. Senate Subcommittee on
Oceans and Fisheries

Senate Committee on Commerce, Science, and Transportation

Hearing on S. 1480

Harmful Algal Bloom Research and Control Act of 1997

with specific comments on

Hypoxia and Nutrient Enrichment

May 20, 1998

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Madam Chair and Members of the Subcommittee:

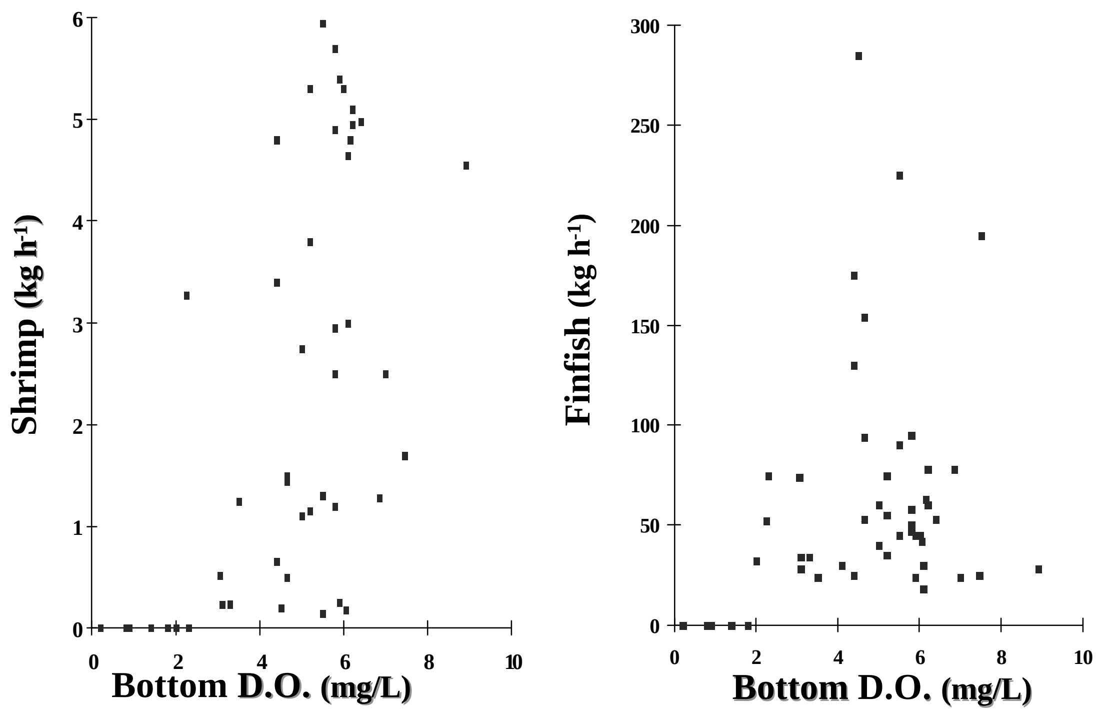
I offer the following material as testimony to your subcommittee on S. 1480 "Harmful Algal Bloom Research and Control Act of 1997" with specific comments on Hypoxia and Nutrient Enrichment as requested by Senator Breaux.

I am a Professor at the Louisiana Universities Marine Consortium in Cocodrie, Louisiana, and have been active in the field of hypoxia and nutrient enrichment for 14 years. I have lead, participated in, or advised several national studies, such as NOAA's National Estuarine Eutrophication Survey and the State of the Coast web site on "Oxygen Depletion in Coastal Waters," regional studies such as the review I did for the Gulf of Mexico Program on Indicators of Eutrophication in the Gulf of Mexico, and the international SCOPE nitrogen project. My specific research focuses on the large zone of hypoxia (= oxygen depletion) in the northern Gulf of Mexico adjacent to the outflow of the Mississippi River, and will provide the majority of the information for one aspect of the White House Hypoxia Assessment for which I am a Team Leader. I am currently the President of the Estuarine Research Federation, a 1300 member society dedicated to research and education in estuarine and coastal waters.

Introduction

Oxygen is necessary to sustain the life of most higher organisms, including the fish, shrimp, crabs and oysters that live in estuarine and coastal habitats. Oxygen from the air normally dissolves into the water to supply the needs of aquatic animals, including those that swim or move about the bottom and those that live in the sediments. When the supply of oxygen to the bottom is cut off or the consumption rate of oxygen exceeds the supply, the oxygen concentrations become too low to sustain most marine animals. This condition of low oxygen is known as hypoxia. The point at which animals suffocate varies, but generally effects start to appear when oxygen levels drop below 2 or 3 mg/l, or ppm. The critical level in the Gulf of Mexico is 2 mg/l based on observational studies of trawl catches that show no fish or shrimp are caught when the oxygen falls below this point.

Hypoxia = Dissolved $O_2 \leq 2$ mg/L (=2 ppm)



(data from Leming and Stuntz, 1984; SW Louis. Coast, June 1982)

The exclusion of organisms or death to those that cannot escape has significant impact on important fisheries, such as the economically important shrimp fishery in the Gulf of Mexico or the striped bass populations in the Chesapeake Bay. Prolonged oxygen depletion can not only disrupt benthic (bottom-dwelling) and demersal (bottom-associated) communities but can also cause mass mortalities of aquatic life. Among other problems, the consequences to coastal commercial fisheries can be disastrous. The occurrence of severe oxygen depletion is a growing concern for U.S. estuarine and coastal waters.

Causes of Hypoxia

Oxygen depletion results from the combination of several physical and biological processes. First, the water column must be physically structured so that the bottom layer is isolated from the surface and the normal resupply of oxygen. Fresher waters derived from rivers and seasonally-warmed surface waters are less dense and sit above the saltier, cooler and more dense water masses near the bottom. Winds and waves will mix the water column, but two-layered systems exist for prolonged periods, especially in the summer, and support the development of hypoxia. Second, there is decomposition of organic matter that reduces the oxygen levels in the bottom waters. Nutrients delivered to estuarine and coastal systems support biological productivity. Essential nutrients for algal growth are nitrogen (N), phosphorus (P) and silicate (Si). Excessive levels of nutrients, however, can cause intense biological productivity that depletes oxygen. The remains of algal blooms and fecal pellets sink to the lower water column and the seabed and become the source for the bacterial decomposition that depletes the oxygen.

Several studies in the United States and worldwide have documented the link between the frequency and volume of summer oxygen depletion to increased nutrient inputs. Many coastal ecosystems have been subjected to changes in nutrient inputs that reflect patterns of land use in their respective watersheds and airsheds. Growth in population, changes in land cover, and increases of fertilizer use and animal husbandry have resulted in two- to tenfold increases in the level of nutrient inputs this century, with particularly dramatic increases since the 1950s. Nutrient enrichment over long periods leads to broad-scale degradation of the marine environment. This degradation is manifested as hypoxia in some instances, but also as decreased water clarity, fish kills, harmful algal blooms, altered food webs, loss of seagrass beds, or loss of important fisheries species.

Scope of the Problem

Oxygen depletion occurs during the spring, summer and fall in over half of the major estuaries in the United States. Differences in freshwater input, point or diffuse nonpoint nutrient loadings, the location of the nutrient inputs, morphology of the estuary and circulation patterns affect the severity of oxygen depletion. Some are clearly overenriched with nitrogen and phosphorus and suffer notable oxygen depletion problems that have been identified for a number of years. Others are beginning to experience the telltale signs of degraded water quality, including hypoxia. Still others are less enriched, but are physically susceptible to oxygen-depleted bottom waters under certain circumstances.

Two surveys, one completed in 1984 and the other in 1996, documented the existence of oxygen depletion in a large number of estuarine and coastal waters of the United States. In the more recent survey, NOAA’s National Estuarine Eutrophication Survey, investigators found oxygen depletion to varying degrees in 71 of the 136 major estuaries along the Atlantic, Gulf of Mexico and Pacific coasts (see attached figures).

U.S. estuaries with hypoxia (specific estuaries are identified in the attached figures.)

Region	% Ests.[1]	% Ests.[2]	Area	Months[3]	Frequency	Depth	Zone[4]
North Atlantic	6%	22%	0-2%	7-9	Periodic	Bottom	SW
Mid-Atlantic	50%	59%	9-22%	6-9	Periodic	Bottom	MX
South Atlantic	16%	62%	4-12%	5-9	Periodic	Bottom/ Through	MX/SW
Gulf of Mexico	66%	84%[5] 86%[6]	12-27%[5] 32-66%[6]	6-10 4-10	Periodic Periodic	Bottom Bottom	MX/SW/TF
Pacific Coast	21%	26%	1-2%	8-10	Periodic	Bottom	MX/SW
Nation	37%	52%[5] 53%[6]	8-19%[5] 21-43%[6]	5-10	Periodic	Bottom	MX/SW

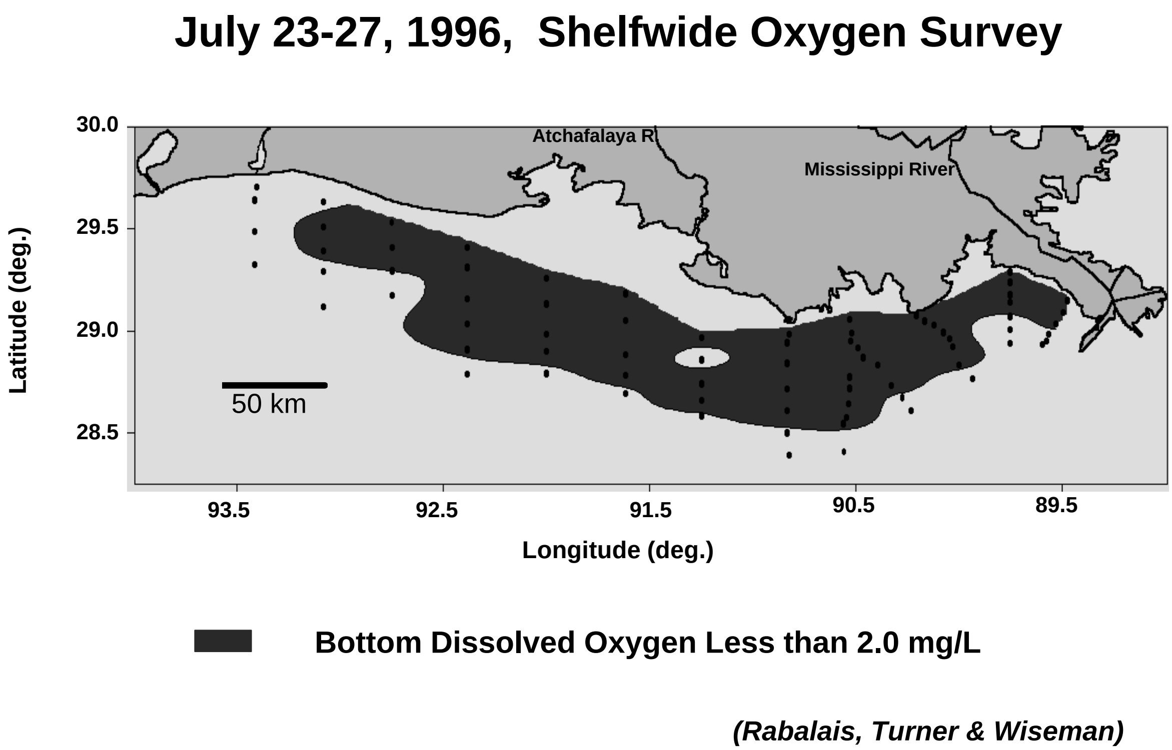
[1] Based on Whitledge (1985), number of estuaries reporting as % of total.
[2] Based on NOAA's National Estuarine Eutrophication Survey, estuaries with hypoxia in part or all of the estuary, number of estuaries reporting as % total. Of all responses, 6 are speculative; 3 in South Atlantic, 2 in Gulf of Mexico and 1 in Pacific.
[3] Months are referred to by number with 1 = January, 2 = February, . . . 12=December.
[4] TF = tidal fresh zone (<0.5 ppt), MX = mixing zone (0.5-25 ppt), SW = seawater zone (>25 ppt).
[5] Does not include the Mississippi/Atchafalaya River Plume.
[6] Includes the Mississippi/Atchafalaya River Plume.

There are distinct regional differences in the occurrence of hypoxia. Most hypoxia occurs in the mid-Atlantic, south Atlantic and Gulf of Mexico regions because of the volume of nutrients discharged and the physical factors that control the processing of the nutrients within the estuaries there. The mid-Atlantic is the most densely populated region. In addition to the sewage-based nutrients that accompany large populations, the significant agricultural activity provides nutrients through runoff. Atmospheric deposition of nitrogen is also a large contributor. In south Atlantic estuaries, the warmer climate is conducive to hypoxia, and agriculture and animal husbandry (hog farms) lead to high organic production that depletes oxygen. In the Gulf of Mexico estuaries, the occurrence of hypoxia is likely due to the warmer climate and high loads of nonpoint source nutrients. The north Atlantic region is not severely affected by oxygen depletion, because the large tidal range helps to flush the bays and there is low population density. The estuaries that experience hypoxia in the north Atlantic region are those with high population density. Similarly, in the Pacific region, hypoxia occurs in estuaries that have a high population density leading to high levels of nutrients or in areas with restricted circulation.

Gulf of Mexico Hypoxia

The largest zone of hypoxia in the United States, indeed the entire western Atlantic

Ocean, is in the northern Gulf of Mexico on the Louisiana continental shelf adjacent to the outflows of the Mississippi and Atchafalaya Rivers. The area, known as the "Dead Zone" in the popular press, extends from the Mississippi River delta westward and onto the upper Texas coast.



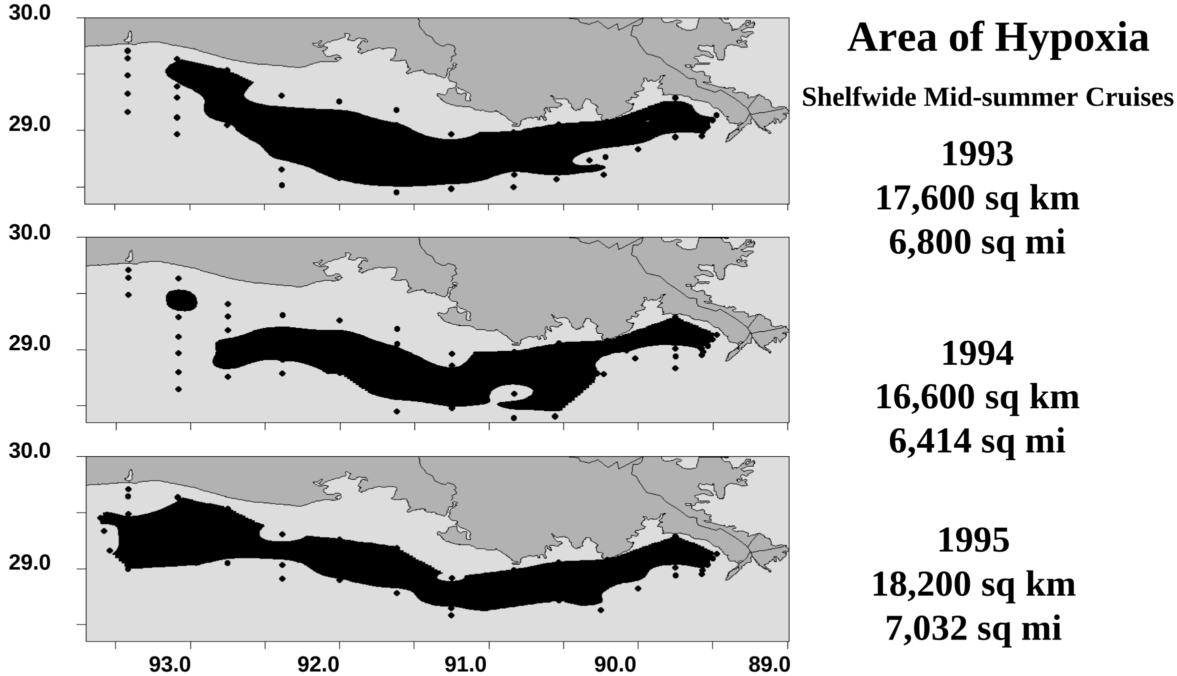
Hypoxia occurs from late February through early October, but is most widespread, persistent and severe in June, July and August. Wind mixing from tropical storms in the late summer and fall and cold fronts in the winter breaks up the hypoxic water mass until it redevelops in the spring.

Hypoxic waters are distributed from shallow depths near shore (4 to 5 m) to as deep as 60 m water depth. During upwelling favorable wind conditions, hypoxic water masses will impinge upon barrier islands often concentrating fish and shrimp and sometimes causing massive fish kills. The distance offshore to which hypoxic water masses are found is contoured by the slope gradient of the continental shelf. On the southeastern Louisiana shelf, where the shelf slopes more steeply towards the Mississippi Canyon, hypoxia extends only 55 km from shore. On the central and southwestern Louisiana shelf, where the continental shelf is broader and the depth gradient is more gradual, hypoxic bottom waters may extend as far as 130 km offshore.

Hypoxia occurs not only at the bottom near the sediments, but well up into the water column. Depending on the depth, hypoxia may encompass from 10% to over 80% of the total water column, but normally 20 to 50%. Very often anoxic bottom waters occur, along with the release of hydrogen sulfide from the sediments.

Since 1985 the distribution of hypoxia on the Louisiana shelf has been mapped during mid-summer cruises (usually late July to early August) during the expected maximal extent of hypoxia. [The studies have been conducted by Drs. Nancy Rabalais of the Louisiana Universities Marine Consortium and Drs. R. Eugene Turner and William J. Wiseman, Jr. of Louisiana State University with significant funding from NOAA.] For the period 1985 to 1992, the zone of hypoxia was usually in a configuration of disjunct areas situated to the west of the deltas of the Mississippi and Atchafalaya River (which carries one-third of the flow), and the size averaged 7,000 to 9,000 sq km.

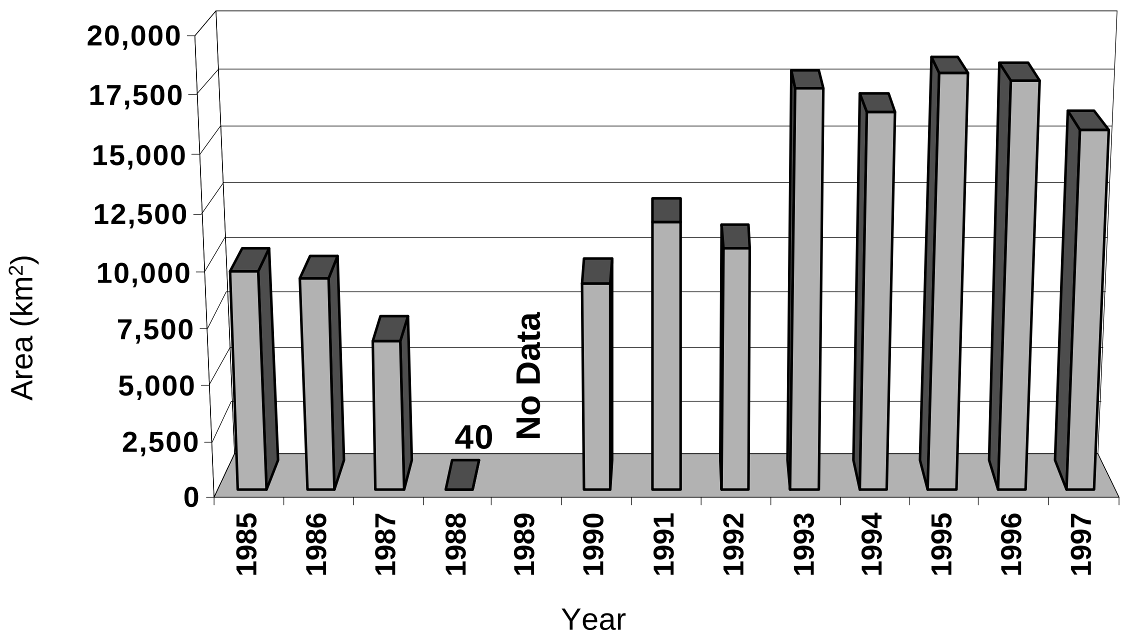
In recent years (1993-1997), the extent of bottom water hypoxia (16,000 to 18,000 sq km) has been greater than twice the surface area of the Chesapeake Bay, rivaling extensive hypoxia/anoxic regions of the Baltic and Black Seas. Prior to the Mississippi River flood of 1993, the hypoxic zone averaged 8,000 to 9,000 sq km, but the hypoxic zones have since been consistently greater than 15,000 sq km. For comparison, the hypoxic zone approximates the size of the state of New Jersey.



(Rabalais, Turner & Wiseman)

Spatial and temporal variability in the distribution of hypoxia is, at least partially, related to the amplitude and phasing of the Mississippi River discharge and the nutrient flux. The effects of the 1993 flood were apparent with the doubling of the size of the hypoxia zone, a larger size that has persisted through 1997. Similarly, during the 1988 drought year, hypoxia bottom waters, while they developed as normal in the spring, did not persist through the summer.

Areal Extent of Hypoxic Zone 1985 - 1997

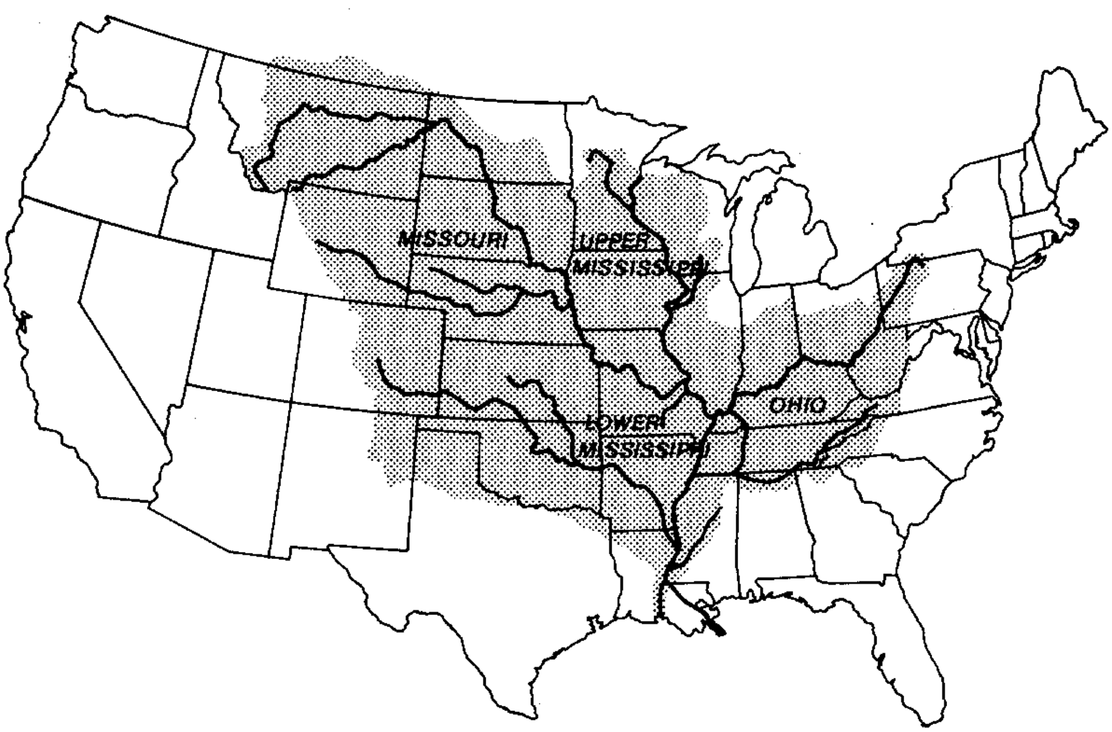


(Data Source: N. Rabalais, LUMCON)

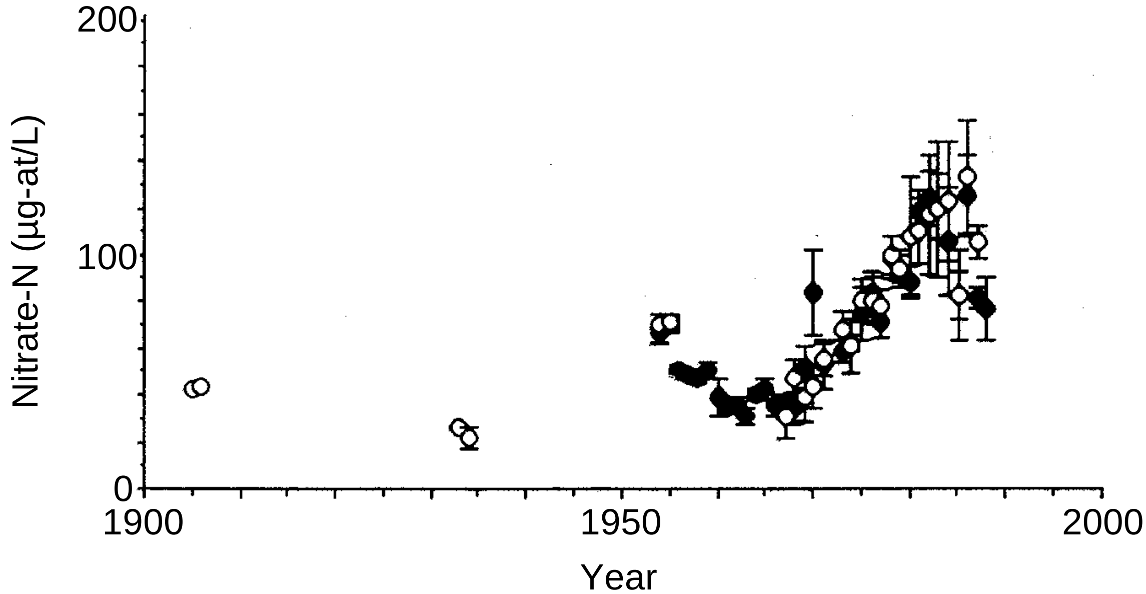
Studies in the northern Gulf of Mexico and Chesapeake Bay, among other systems, provide evidence that the timing, spatial extent and severity of oxygen depletion, as well as changes over time, are linked to freshwater discharge and nutrient flux. In both the northern Gulf of Mexico and Chesapeake Bay, seasonal nutrient fluxes stimulate biological productivity in the spring , resulting in organic matter flux to bottom waters that is usually sufficient to cause bottom water oxygen depletion during the summer. Timing of Mississippi River discharge and nutrient flux, surface water production, and oxygen depletion are strongly correlated on the southeastern Louisiana shelf.

The strength of these relationships allows for the reconstruction of changes in surface water productivity and bottom water hypoxia over time through the analysis of sediment cores. In the northern Gulf of Mexico, as well as many other estuaries and coastal areas, there is evidence of decade- and century-long increased in nutrient enrichment, hypoxia and eutrophication. Analysis of sediments from the continental shelf adjacent to the Mississippi River clearly show that the productivity of the surface waters and severity of hypoxia have increased as the nitrogen level in the river has risen.

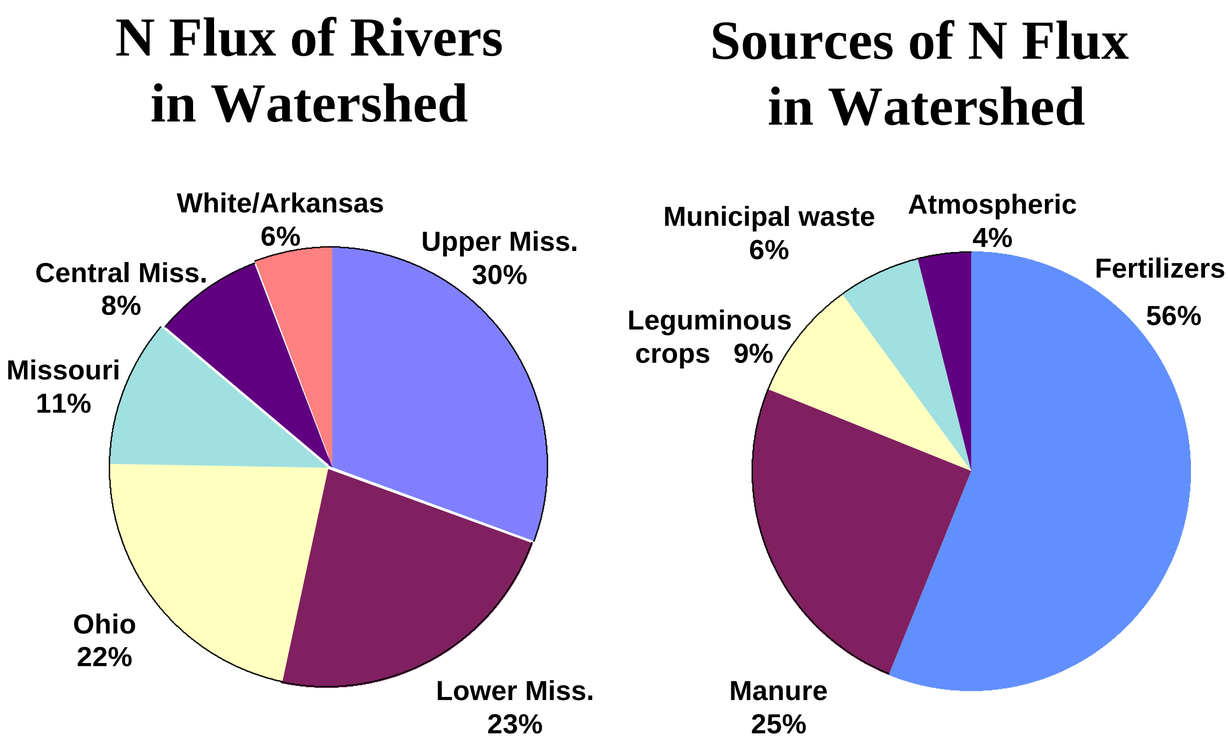
The Mississippi River is the dominant source of freshwater and nutrients to the northern Gulf of Mexico. The watershed is the largest in the United States (41% of the area of the contiguous 48 states), and has undergone massive transformations in the last 200 years. The river has been shortened by 220 km in an effort to improve navigation, and has a flood-control system of earthwork levees, revetments, weirs, and dredged channels for much of its length. Water quality in streams, rivers, lakes and coastal waters will change when watersheds are modified by alterations in vegetation, sediment balance, conversion of forests and grasslands to farms and cities, and increased anthropogenic inputs through fertilizer applications, sewage disposal, or detergents, and atmospheric deposition. Water quality in the Mississippi River has certainly changed this century as a result of these watershed changes.



Mississippi River nutrient concentrations and loadings to the adjacent continental shelf have change dramatically this century, with an acceleration of these changes since the 1950s. The mean annual concentration of nitrate in the lower Mississippi River was approximately the same in 1905-06 and 1933-34 as in the 1950s but doubled in the last 35 years. The mean annual concentration of silicate was approximately the same in 1905-06 as in the 1950s, then it declined by 50%. Although the concentration of phosphorus appears to have increased since 1972, variations between years are large. The changes appear to have plateaued since the mid-1980s, but trends are masked by increased variability in the 1980s and 1990s data. The seasonal peaks in nitrate concentration have also changed this century from no pronounced peak in nitrate concentration earlier this century to a current peak in spring. The increase in nitrate concentration in the spring is important, because much of the biological productivity stimulated by nitrogen in the spring is eventually responsible for the development of hypoxia. Thus, not only has the nitrogen delivered to the northern Gulf increased, the increased flux in the spring aggravates an already overloaded system. The water quality changes in the Mississippi River are not unique among U.S. and world rivers. The Mississippi is one of several rivers in which the concentrations and proportions of nitrogen, phosphorus and silicate have changed over many decades as a result of anthropogenic activity in the watershed.   The result is degraded water quality, including hypoxia and harmful algal blooms, in those coastal areas adjacent to anthropogenically-altered riverine discharges.



Mean annual concentration of nitrate in the lower Mississippi River .

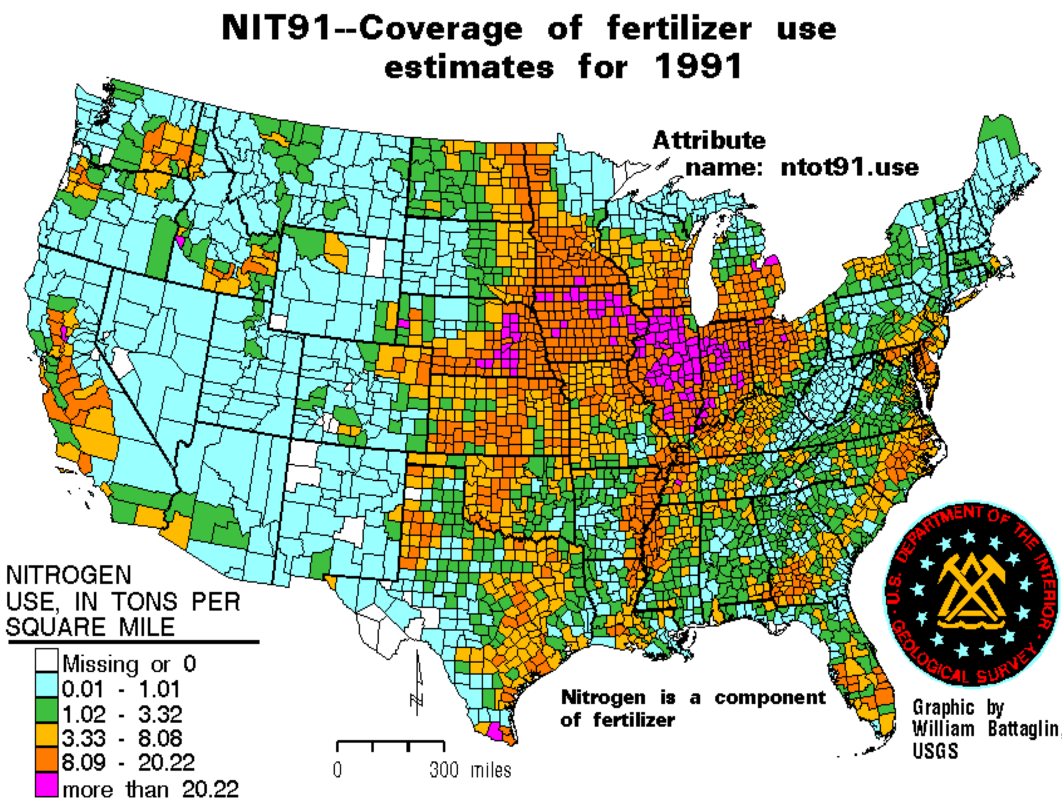


(derived from Meade (ed.) 1996)

Sources of nitrogen to the Mississippi River watershed.

Knowing the linkages between river discharge and nutrient flux and the development of hypoxia as well as how the ecosystem has changed over time as riverine discharge of nutrients has changed, provides ample evidence to implicate the increases in nutrients, particularly nitrogen, to a worsening of the hypoxia problem in the northern Gulf of Mexico and other regions of the U.S. and the world. The next step is in adequately identifying the sources of the increased nutrients.

More than 70% of the total nitrogen delivered to the Gulf of Mexico by the Mississippi River originates above the confluence of the Ohio and Mississippi Rivers. This nitrogen is transported over distances of more then 1000 miles. The Upper and Central Mississippi Basins account for the largest quantity of nitrogen delivered to the Gulf. Approximately 90% of the nitrogen delivered to the Gulf from the Mississippi River originates from nonpoint sources consisting primarily of nitrogen in agricultural runoff and atmospheric deposition. The relative inputs through agricultural practices are relatively higher for the Mississippi River watershed than for other areas of the U.S. (e.g., southeast and northeastern U.S.) where atmospheric inputs are a higher percentage. The importance of freshwater in dictating the physical structure that supports hypoxia development and maintenance is clear. The fact that the discharge of the Mississippi River has been relatively constant through a channelized system since the early 1900s, points to changes in water quality (i.e., increases in nitrogen flux) as the factor most closely related to the observed changes in biological responses in the marine ecosystem. Thus, management options should be aimed at reducing nonpoint nutrient sources and/or maximizing the natural processes of nutrient retention and transformation within the watershed.



Gulf of Mexico Resources at Risk

Louisiana leads the Gulf of Mexico in production and landings of commercial and recreational marine resources. Louisiana is second only to Alaska in fishery value and tonnage landed among all U.S. states. The fisheries depend on species for which parts of the life cycle overlap with the expanding hypoxia zone on the shallow continental shelf. Increasingly, each year, spawning grounds, migratory pathways and feeding areas of fishery species, such as shrimp, menhaden, red drum, sea trout, southern flounder and red snapper coincide with hypoxic waters. Moreover, the fishing grounds for shrimp, menhaden, red snapper and others are diminished by the hypoxic zone. As the size of the zone expands, productive habitat and fishing area decreases. Evidence indicates that fishery species avoid hypoxia, and Louisiana fisheries are subsequently disrupted. Both the abundance and the biomass of fishes and shrimp are significantly less where oxygen concentrations in bottom waters fall below 2 mg/l. The ability to detect and avoid water with low oxygen leads to a blocking effect on shrimp emigrating from inshore nurseries to offshore feeding and spawning grounds. Not surprisingly, a negative correlation between shrimp catch and the presence of hypoxia has been observed. Since hypoxia impedes offshore movement of juvenile shrimp, the nearshore concentration of shrimp is always high. The amount of fishing effort directed to catching shrimp is always much larger in nearshore than offshore Louisiana, and is particularly apparent when compared to nearby Texas. Since the nearshore catches are mainly of young, small shrimp, productivity through growth to a larger size is lost. Production models conservatively estimate that several million of pounds of shrimp are lost through curtailed growth due to early harvest alone each year. Losses in production due to lost feeding grounds have not been estimated, but they are predictably large due to the large amount of area impacted (as much as 50% of the coastal shelf of Louisiana). These losses in fisheries productivity are exacerbated when the hypoxic zone expands in space and time.

Research Needs

While we know much about the linkages of Mississippi River nutrients and hypoxia in the northern Gulf of Mexico, and similar relationships for other estuaries and coastal water bodies, much remains to be discovered. Further research in the Gulf of Mexico needs to be directed at better defining the physics that controls the distribution of hypoxia, better defining differences across the shelf in timing, extent and severity of hypoxia, more retrospective analyses from more areas of the shelf, fisheries impacts, benthos and zooplankton impacts, and economic analyses. Lines of research that investigate the temporal and spatial differences in phytoplankton abundance and community composition in response to varying nutrient concentrations and ratios and the subsequent effects on carbon flux and higher trophic levels will increase both knowledge of the dynamics of hypoxia but also harmful algal blooms.

The current NOAA FY 1999 budget request for $1.4 million of additional funds to support a new NOAA effort will build upon the COP NECOP(Nutrient Enhanced Coastal Ocean Productivity) program findings and the current assessment effort. An important element in further research is the continuation of the long-term data base that has been garnered since 1985 in the Gulf of Mexico and the water quality network within the Mississippi River watershed since the 1950s. Without continued monitoring of hypoxia in the offshore area and riverine nutrient concentrations, transport and flux, the ability to define success following nutrient intervention will be impossible.

Within the Mississippi River watershed, there is an equal need for research in such aspects as better defining sources of nutrients, the transport and transformation of nutrients within the watershed and in transit to the Gulf of Mexico, the relationship of agriculture practices and nutrient loads, the effects of remedial landscape change such as riparian buffer strips and constructed wetlands, and the economics of best management practices that reduce the loads of nutrients to the streams and rivers in the Mississippi River watershed. Similar suites of studies are justified for examining hypoxia in the many smaller bays, estuaries and coastal water bodies that are currently affected, especially those where either the spatial extent is a large percentage of the aquatic habitat or the levels are sufficiently low enough to endanger living resources.

An important aspect of research directed at hypoxia is that the program integrate academic scientists with NOAA scientists, that the program be administered in a scientifically rigorous manner, that a framework for hypoxia research be developed, and that the development of the framework involve the scientific community.

Management Issues

The importance of research that addresses the potential causes and timing of oxygen depletion, the linkages with nutrients, and the sources and fates of nutrients in the river is that the data acquired can then be used to develop the appropriate management strategies.

The current White House Committee on Environment and Natural Resources Hypoxia Assessment will synthesize what is known about hypoxia, its causes and effects, the sources of the nutrients, potential mechanisms for reducing nutrient loads to the Mississippi River and the Gulf of Mexico, and the economics of effects and remedial activities. One aspect of the study will identify effective, cost-efficient nutrient management strategies that could be implemented soon and into the future throughout the watershed. The Mississippi River/Gulf of Mexico Watershed Nutrient Task Force will use the results of the CENR report to suggest alternative solutions to the hypoxia problem. There are reasons to be optimistic about the potential solutions to reducing nutrient loads and alleviating hypoxia.

There are several success stories for improvement of estuarine and coastal ecosystems in response to nutrient abatement in the watershed or in direct discharges to the system . Nutrient management and intervention to reduce nutrient loads, particularly phosphorus, in Tampa Bay has met with successes in ecosystem restoration, including improved water clarity, reduced instances and biomass of cyanobacterial blooms, expansion of seagrass beds, increased catch of seagrass dependent fishes, such as the highly valued commercial and recreational speckled sea trout, and an improvement in dissolved oxygen conditions in bottom waters.

The magnitude of restoration needed to affect changes in much larger coastal systems with much larger watersheds, such as the Chesapeake Bay, Long Island Sound, the Baltic Sea and the northern Gulf of Mexico is daunting. Still, multi-state and multi-national agreements and cooperation are aimed at just that in the case of the first three. Chesapeake Bay has been the focus of both intensive research on cultural eutrophication, including hypoxia, and extensive efforts to reduce nutrient inputs responsible for it. Strong public support and political commitment have allowed for progress in reducing nutrient inputs to Chesapeake Bay, particularly from point sources. Reductions in controllable nonpoint nutrient sources, however, have been less successful.

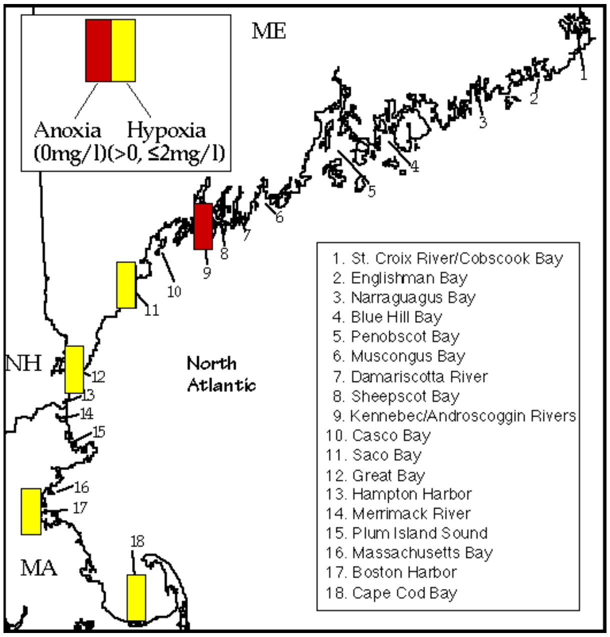
The lessons to be learned from the Chesapeake Bay experience and other areas of the world are (1) the degradation of water quality and increase in oxygen stress occurred over decades, (2) multi-level and multi-institutional support is required to institute nutrient management schemes, (3) many years will pass before the results of implementation of nutrient controls will be seen in nutrient concentrations of aquatic systems, including the coastal ecosystem, (4) biological restoration will also require a long time to respond to the changes, (5) natural variability in climate might mask restoration because of fluctuations in freshwater discharge and the nonpoint sources of nutrients carried with it, (6) restoration of ecosystems following nutrient abatement is achievable, and (7) benefits accrue to multiple facets of society.

Comments on S. 1480

The bill before the committee seeks to further research, monitoring, education and management activities in relation to harmful algal blooms. I fully endorse these actions, given the seriousness of the HAB problem and the evidence for an actual increase of the problem. The increase in HAB outbreaks is paralleled by increases in all symptoms of degraded coastal water quality, such as turbid waters, fish kills, and hypoxia and anoxia. The relationships between human activities that modify the landscape and load the streams with excess nutrients and the degradation of estuarine and coastal waters is clear. As populations increase in the coastal zone and increasing pressures are placed on the landscape, nutrient loads will likely increase and coastal waters will continue to be threatened.

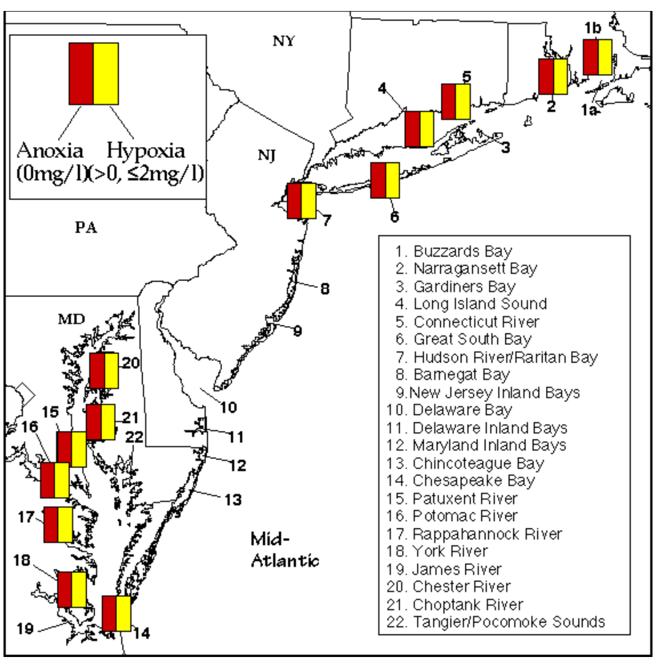
The funds provided by S. 1480 seem adequate for supporting HAB research and management. To deal with the hypoxia problem in the Gulf of Mexico and the many other estuarine habitats of the U.S., however, would require expansion of scope of the wording of the document as well as additional funding specific to hypoxia research. The resources identified are certainly not enough to focus on both HABs and hypoxia nationwide. The Gulf of Mexico hypoxia problem needs to be identified specifically and adequately supported funds to facilitate research and nutrient management.

Madam Chair and Members of the Committee, I thank you for this opportunity to come before you and offer testimony on aspects of hypoxia and nutrient enrichment, especially with regard to the Gulf of Mexico. The problem is not specific to the Gulf of Mexico, but exists nationwide. The Gulf problem, however, exceeds all others in magnitude and potential for fisheries resources impacts. It was my pleasure to bring to you information that has culminated from my many years of research on hypoxia as well as the collective wisdom of numerous scientists that have been focused on the problem.



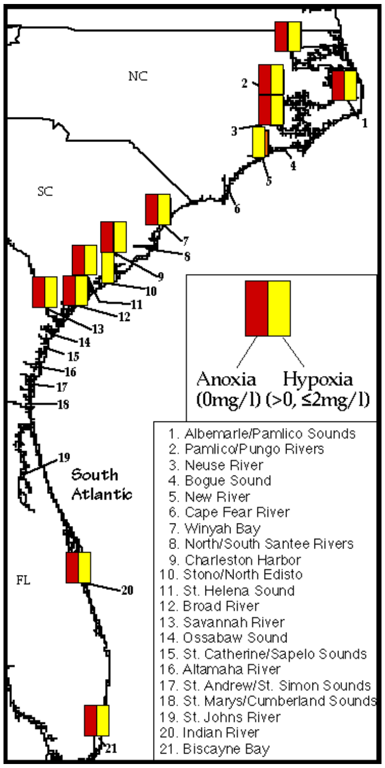
Existing Conditions for Oxygen Depletion, North Atlantic Region

Source: NOAA's Estuarine Eutrophication Survey



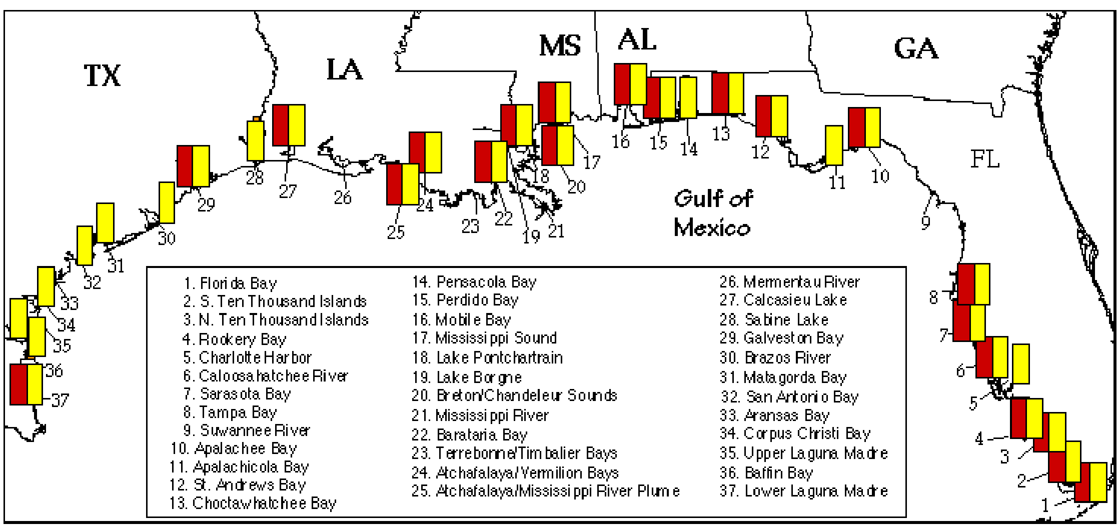
Existing Conditions for Oxygen Depletion Mid Atlantic Region

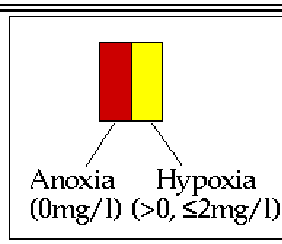
Source:
NOAA's Estuarine Eutrophication Survey



Existing Conditions for Oxygen Depletion,
South Atlantic Region

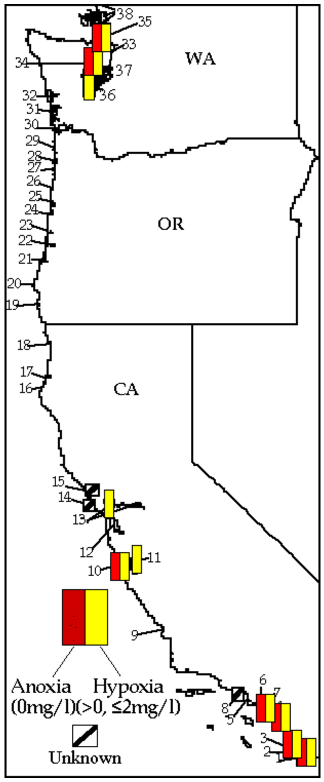
Source: NOAA's Estuarine Eutrophication Survey





Existing Conditions for Oxygen Depletion,
Gulf of Mexico Region

Source: NOAA's Estuarine Eutrophication Survey



Existing Conditions for Oxygen Depletion, Pacific Region

Source: NOAA's Estuarine Eutrophication Survey